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LEGUMES IN CROPPING SYSTEMS

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Legumes in Cropping Systems

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INTRODUCTION

Farmers generally know that legumes perform an important function in the maintenance of fertility, but how to apply to best advantage what is known about them is not generally understood or practiced.

A great many people believe that the growing of legumes increases or maintains the productivity of any soil for non-leguminous crops, even tho the legume crop is harvested and no manure made from feeding it is returned to the soil. Under certain conditions with certain legumes, this is true. For example, a soil rich in mineral nutrients, in which nitrogen has been reduced to a low level, may gain considerable nitrogen from the stubble and large root system of legumes like red clover and biennial sweet clover. These crops also make considerable growth the year of seeding that is usually left on the land or grazed. Also, in the case of red clover, there is often considerable growth after the main crop is harvested that is often grazed or left on the ground. The roots of these plants weigh from one-third to one-half as much as the tops, while the percentage of nitrogen in the roots is more than four fifths as great as in the tops. In contrast with red clover and sweet clover are soybeans and cowpeas—annual legumes whose roots weigh only about one-sixth as much as the tops, while the percentage of nitrogen in the roots is only about two-thirds as great as in the tops.

* The experimental results used in this bulletin are taken from work conducted by various members of the Department of Agronomy, without attempting to indicate specifically the work done by each member. Practically all members of the staff in soils and crops have participated in it.

It is well established that legumes, even tho inoculated, fix nitrogen from the air only to the extent that the soil supply is insufficient for their needs.[1] Since this is true, the roots and stubble of legumes with large root systems such as red clover and sweet clover, may add nitrogen to soil of low or medium nitrogen content, notwithstanding that the crop is removed. Such legumes as cowpeas and soybeans, however, with small root systems and a smaller percentage of nitrogen in the roots than in the tops, could do this only where the nitrogen content of the soil is very low. This statement is supported by experimental results given in Tables 1 and 2. Soybeans and cowpeas can, of course, be used to increase nitrogen in the soil by turning them under, hogging them down, returning the straw when threshed, or returning the manure made by feeding them, and properly protecting the soil with cover crops. Obviously, the best legumes, when harvested, can maintain nitrogen in most soils only at a moderate level, while such legumes as cowpeas and soybeans, when harvested, deplete the nitrogen supply, unless the soil is very low in nitrogen, probably too unproductive for profitable use. Even on such soil, soybeans and cowpeas so handled cannot increase the nitrogen content very much.

It is quite certain that large losses of nitrogen from leaching often occur when cowpeas and soybeans are hogged down or turned under and followed by a cover crop, for the reason that the usual winter cover crop of grain does not make enough growth to utilize the available nitrogen. The tops and roots of a crop of soybeans yielding a ton of hay contain nearly 60 pounds of nitrogen, while the growth of a cover crop of grain seeded at the usual time contains about 10 to 20 pounds of nitrogen per acre at the end of the fall growing season, which is very likely not as much soluble nitrogen as usually develops in the soil under these conditions before growing weather ceases.

[1] New Jersey Agr. Exp. Sta. Bul. 436. The relation of soil nitrogen to nodule development and fixation of nitrogen by certain legumes. G. Giobel. 1926.

Early seeding of the cover crop would increase the nitrogen saved from leaching.

The annual lespedezas are legumes from which large losses of nitrogen may occur. As they mature before growing weather is over, available nitrogen subsequently develops, much of which may be lost by leaching unless something is seeded with them that will remain green thruout the winter and start growth early the next spring, for these lespedezas do not make very much spring growth until rather late. All annual lespedezas should either have a perennial grass seeded with them or the land should be seeded to a winter grain as early in the fall as is practicable. The ground can usually be sufficiently prepared for seeding by disking. If proper care is used in harvesting or pasturing lespedeza, usually enough seed is left on the ground for a stand the next spring.

An influence on nitrogen fixation by legumes that is not fully understood and that may be of far greater importance than is commonly believed, is the effect of growing a perennial or biennial grass with the legume, altho the associated legume may be a biennial or perennial. It is possible that the grass competing for soil nitrogen may force the legume to take a greater part of its supply from the air than if no grass were present. Also, the grass may prevent considerable leaching of nitrogen under a biennial or perennial legume that may take place when the legume is grown alone. Unpublished data from lysimeter experiments at the Kentucky Agricultural Experiment Station indicate that quite large losses of nitrogen by leaching may occur under some conditions with white clover and second-year red clover sods when grown alone, but that they are largely prevented when bluegrass is grown with them. Even alfalfa showed some loss, which was largely prevented by growing bluegrass with it. Another advantage of a combination of grass and legumes is that, grown upon a soil well supplied with mineral nutrients, the grass may be brought up to a protein content equal to that of the legume. Data from some of our nitrogen fixation studies have shown this to be true under certain conditions.

A vigorous sod of grass and legumes may supply the most favorable form of nitrogen for the production of tobacco. It has long been recognized by growers of Burley tobacco that the ideal soil condition for producing a high yield and quality of tobacco is a vigorous bluegrass sod on well-drained land. The vigorous sod of course depends upon a plentiful supply of nitrogen, which means a large amount in the vegetation turned under. The growth of tobacco on such land seems to indicate that nitrogen is converted into available form as needed by the crop. Conceivably there is a very great advantage in having the nitrogen in this form, for weather conditions that favor good growth of the crops favor nitrification and, conversely, weather conditions that slow up the growth of crops slow up nitrification; consequently available nitrogen is developed as needed.

When one undertakes to supply nitrogen in readily available form, the proper amount to apply cannot be determined, because weather conditions cannot be predicted. Too much may overdevelop the crop, set up a larger demand for moisture than is available, and cause a lower yield than if the nitrogen had not been applied. It may be possible, by a number of small applications, to avoid this difficulty. A single small application of soluble nitrogen at planting time may decrease the yield, particularly of corn, by stimulating early growth and setting up a larger requirement for water and nitrogen than can later be met, because of drouth or lack of soil nitrogen.

Tobacco growers on the sandy soils of the flue-cured–tobacco area recognize the critical importance of the nitrogen supply for the crop and use a mixture of readily available inorganic nitrogen materials, like nitrate of soda, and such organic nitrogen materials as dried blood and cotton seed meal, which later become available upon nitrification. May not nature's way, as manifested in a vigorous grass and legume sod, be the best way to supply most of the nitrogen to crops, to be supplemented, if necessary, by readily available nitrogen applied when symptoms indicate the need?

Another important relation of legumes to the maintenance

of productivity, that is often overlooked is that they make a very heavy draft upon the mineral nutrients of the soil, particularly calcium (lime), potassium and phosphorus. If the manure from feeding the legumes is not returned or if fertilizers and lime are not used, serious deficiencies in mineral nutrients may occur. For example, a ton of alfalfa hay contains about 5 pounds of phosphorus and 35 to 40 pounds of potassium, whereas the grain and stalk of a 50-bushel corn crop contains 10 to 12 pounds of phosphorus and about 35 pounds of potassium. Alfalfa, after the first cutting of the season, has only about five weeks in which to get its supply of these nutrients, whereas a corn crop has much longer. A potassium deficiency may develop for alfalfa long before it shows on corn and other crops harvested once a year. A five-year stand of alfalfa yielding 3 tons a year is more exhaustive of potassium than corn grown continuously on the land for fifteen years, yielding 50 bushels per acre per year. Five hundred pounds of superphosphate per acre for alfalfa is only 33 pounds per ton of alfalfa of the above length of stand and yield. No one would think of fertilizing corn, or any other crop of one yield per year, so lightly as 33 pounds of superphosphate per acre.

A top-dressing test was made at the Western Kentucky Substation beginning in the spring of 1931, on four- and five-year-old alfalfa that had been limed at the rate of 2½ tons of limestone per acre and fertilized with superphosphate at the rate of 400 pounds per acre, when sown. Three or more cuttings of hay had been removed each year after the year of seeding, and the alfalfa had begun to thin out. The tests consisted in top-dressing (1) with 500 pounds of superphosphate per acre, (2) with 500 pounds of superphosphate and 200 pounds of muriate of potash, compared with a check without top-dressing. The tests were made in quadruplicate and located in two fields. Only one application of fertilizers was used in the three years of the test, and nine cuttings were made. The total yield for all cuttings of alfalfa not top-dressed was 15,012 pounds per acre. Phosphate top-dressing increased this yield by 6480 pounds, while potash in the top-dressing further increased the yield by

618 pounds. About half of the total increase for phosphate was in the first year. This soil is quite low in phosphorus, but rather high in potassium.

It sometimes happens that tobacco grown on land that has been in alfalfa for several years is injured by potassium starvation, caused by the heavy draft alfalfa has made upon this element.

Some soils which have been made productive by the use of lime and phosphate and the growing of legumes will sooner or later become deficient in potassium, even for such crops as corn and wheat, unless manure is carefully saved and returned to the land. In fact, the increase in yield due to the lime, phosphate and legume treatment hastens the depletion of potassium and other elements.

REVIEW OF DISCONTINUED EXPERIMENTS PREVIOUSLY REPORTED

Legumes in Continuous Culture and Rotation. The value of legumes planted in corn at the last cultivation, under Kentucky conditions, is not so great as has generally been believed, because moisture conditions are such that good stands and good growth are difficult to obtain. Particularly is it difficult to get a stand of crimson clover, because the seeds germinate so quickly that a light rain causes them to sprout, after which they perish when the soil dries out around them.

Beginning in 1911, two plots of continuous corn were used in an experiment on the Experiment Station farm at Lexington to test the effect of legumes planted at the last cultivation of the corn (see Bulletin 331). The test was continued thru 1923. The yields of corn on the two plots the first year (a dry one), were 25.7 bushels and 24.7 bushels. A legume catch crop was seeded on the second plot each year thereafter. A winter cover crop of grain was used, except when crimson clover was the legume catch crop, and the cornstalks were left on the ground, beginning with 1915. Various legumes were tried. Cowpeas were seeded six years; crimson clover was used once after cowpeas failed, and twice as the only seeding. Once the

plot was divided equally between crimson clover and cowpeas, and once between cowpeas and soybeans. Vetch was used once. The average yield of corn for 1912-22 on the legume plot was 32.6 bushels, and 29.7 on the non-legume plot—not enough difference to pay for seed and labor in planting the catch crops.

The legume plot was limed in 1923 before planting corn. The yields of the two plots for that year were 48.2 bushels and 30.2 bushels, respectively, for the limed legume plot and the non-legume plot. Wheat was sown on them in the fall of 1923, and the following spring they were seeded to a mixture of sweet clover, red clover, and alsike clover. Sweet clover persisted on the limed plot only. The yields of hay were 5340 pounds and 4500 pounds, respectively. Corn followed in 1926, with yields of 62.9 bushels and 63.8 bushels, as compared with 74.9 bushels and 76.1 bushels on the limed and unlimed plots in the adjacent three-year rotation of corn, wheat and clover mentioned in the next paragraph. Thus one legume crop in rotation restored the land to comparatively high productivity for corn. Corn grown on unfertilized land nearby, that had been in continuous culture since 1920 yielded 33.6 bushels in 1926, but had yielded 70 bushels in 1920.

At the same time, on plots near the continuous culture plots, a three-year rotation of corn, wheat and clover was started in which cornstalks and wheat straw were returned, beginning in 1915. The yield of the first corn crop (1911) was 32.1 bushels per acre. The average yield for 1912–22 was 54.8 bushels, compared with 32.6 bushels on the continuous corn plot with a legume catch crop.

Nearby, on another set of plots, a four-year rotation of corn, soybeans, wheat and clover was started at the same time. No manure or crop residues were returned. The yield of corn was 30.7 bushels in 1911. For 1912–22 the average yield was 54.4 bushels.

In another test of corn in continuous culture, started in 1920 on the Experiment Station farm at Lexington, the yield of corn the first year was 64.9 bushels on a plot on which a legume was not used, and 67.7 bushels on an adjoining plot on

which cowpeas were seeded each year thereafter. The experiment was continued thru 1931. The average yield of corn for ten crops (exclusive of the first one and a failure in 1930 because of drouth) was 26.7 bushels on the non-legume plot and 34.4 bushels on the plot with cowpeas as a catch crop—a difference of 7.7 bushels. The cornstalks were removed and a winter cover crop of rye was used on both plots.

On a set of three plots adjacent to the foregoing experiments, a rotation of corn, wheat and clover was started at the same time. The average yield of corn for the first three years in this rotation, on unmanured land, was 41.9 bushels, compared with 44.5 bushels on the legume plot just mentioned, in continuous corn culture. The average yield of corn for ten years, 1921–31 (except crop failure of 1930), in rotation, was 51 bushels, as against 34.4 bushels on the legume plot in continuous corn. In this period clover failed three times and soybeans were used instead. They are not so effective as clover in improving soils.[2]

In 1914 an experiment[3] was started on two sets of plots of ten each. The average yields (43.2 bushels), of corn on the two sets of plots were the same the first year. On one set of plots a two-year rotation of corn and soybeans was used, leaving the cornstalks on the ground and returning the straw from the soybeans and using a winter cover crop of rye each year. On the other set of plots, corn was grown continuously, but the stalks were removed and no cover crop was used. Certain plots in both sets were similarly fertilized, with liberal applications. In the rotation, the average yield of corn from all plots for seven crops (alternate years 1915–27) was 54.7 bushels per acre, while for the same years, in the continuous culture, the average yield was 42.4 bushels. On the three unfertilized plots in the rotation, the average yield was 53.1 bushels, while on the three unfertilized plots in continuous culture it was 37.5 bushels

[2] See Kentucky Experiment Station Bulletin 331, Soils and Fertilizer Experiments, Experiment Station Farm, Lexington, 1932, for further details on the foregoing experiments.

[3] For details of this experiment see the article, "Renewed Experiments," in Bulletin 331, Kentucky Experiment Station.

for the same years. The average yield for the six plots in rotation not receiving nitrogen fertilizer was 53.3 bushels per acre, and for similar plots in continuous culture it was 38.7 bushels. The average yield in rotation for four plots receiving 160 pounds of nitrate of soda per acre alone or in combination with other fertilizer ingredients was 56.6 bushels per acre, and for similar plots for the same years in continuous culture it was 48.0 bushels per acre. The average yield of soybeans in the rotation was 14.3 bushels per acre.

While it cannot be determined to what extent the larger yields in rotation were due to rotation as such, how much to the residues returned, and how much to the cover crop, the experiment is a good illustration of the value of the combined practices in the rotation as against continuous culture with the land unprotected. The experiment also shows that soybeans can be so used as to maintain a fair nitrogen supply. The land on which these experiments were conducted was almost level, so that there was no serious erosion with continuous corn culture.

Soybeans are often planted with corn for hogging down. The Kentucky Experiment Station conducted tests, for from four to seven years, with soybeans planted with corn in the following ways, the tests being made in triplicate each year:

1. A hill of beans in each hill of corn (seven years).
2. Two hills of beans to each hill of corn, between hills (four years).
3. Drilled thick in corn rows (six years).
4. Alternate rows of corn and beans (five years).

The average yields of beans in the four methods were 3.7 bushels, 5.0 bushels, 10.8 bushels, and 10.2 bushels per acre, respectively. In each case the yield of corn was reduced about 2 bushels for each bushel of beans produced. If the beans and corn are hogged down and a grain cover crop is seeded early, the nitrogen fixed by the beans can be largely saved and the combination will be more valuable than corn alone, both for the hogs and for soil conservation.

There are many experiments on the soil experiment fields thruout the State that illustrate the extent to which soil

can be improved thru the use of legumes in rotation and the practical use of manure, once the land has been limed and fertilized. As an illustration, yield results are given from two sets of plots of the Campbellsville experiment field, which was begun in 1919. The rotation was corn, wheat and mixed grass and legumes. One set of plots was limed at the rate of 4 tons per acre in two applications of 2 tons of ground limestone each, between 1919 and 1923, and superphosphate (16 percent) was used on them at the average rate of 200 pounds per acre per year thru 1931, after which it was used at the rate of 100 pounds. No lime or fertilizer was used on the other set of plots. No manure was used until 1926, when it was applied at the rate of 5 tons per acre for corn on each set of plots. Six tons of manure per acre were applied to each set for corn in 1927, and 5 tons in 1928. Since then it has been applied to each set in amounts equal to the weight of the three crops harvested the previous year, wheat grain excepted. The yields obtained are given in Table 1.[4]

The hay mixture thru 1924 was red and alsike clover. Timothy was added in 1925, lespedeza in 1926, and alfalfa in 1927. Each was continued after its introduction. Second cuttings were obtained in 1929 and from 1933 to 1936 and are included in the above averages. In the later years some good yields of hay were obtained the year of seeding, but they are not included in the averages.

Three fields are required to accommodate a three-year rotation if each crop is to appear each year. Four and six-tenths tons of superphosphate and 12 tons of limestone have been used per three acres. From 1919 to 1936 this treatment has produced, on the three-acre basis, an increase of 434 bushels of corn, 118 bushels of wheat, and 15 tons of hay, exclusive of cuttings the year of seeding. Allowing 50 cents a bushel for corn, 75 cents for wheat, and $10.00 a ton for hay, the increase on three acres was worth $455 in round numbers, while the superphosphate at

[4] The first-year crops are not included. Corn failed in the drouth of 1930. There were two wheat failures and two hay crop failures. For details of the experiments see Kentucky Experiment Station Bulletin 322, Report on Soil Experiment Fields, 1931.

TABLE 1. Average yield per acre in a rotation of corn, wheat, and legumes and grass mixture.

	No Limestone or Superphosphate	Limestone and Superphosphate
Ave. first three corn crops	23.7 bus.	42.0 bus.
Ave. first three wheat crops	2.8 bus.	6.7 bus.
Ave. first three hay crops	860 lbs.	2303 lbs.
Ave. first three manured corn crops (1926-28)	35.6 bus.	62.5 bus.
Ave. three wheat crops (1927-29-30)	2.7 bus.	8.2 bus.
(Wheat failed in 1928)		
Ave. three hay crops (1928-30)	1170 lbs.	3910 lbs.
Ave. last three corn crops (1934-36)	37.3 bus.	63.9 bus.
Ave. last three wheat crops (1934-36)	2.6 bus.	13.2 bus.
Ave. last three hay crops (1934-36)	2237 lbs.	4957 lbs.
Ave. first eight corn crops	24.6 bus.	50.1 bus.
Ave. last eight corn crops	35.5 bus.	64.3 bus.
Ave. sixteen corn crops	30.0 bus.	57.2 bus.
Ave. first seven wheat crops	3.6 bus.	9.8 bus.
Ave. last seven wheat crops	5.9 bus.	16.5 bus.
Ave. fourteen wheat crops	4.8 bus.	13.2 bus.
Ave. first seven hay crops	1076 lbs.	3490 lbs.
Ave. last seven hay crops	2059 lbs.	3953 lbs.
Ave. fourteen hay crops	1568 lbs.	3720 lbs.

$18.00 per ton and limestone at $3.00 per ton cost $120, a gain of $335, or nearly $6.25 per acre per year. It should be remembered that this includes the lower yields at the beginning of the experiment. Also, by test, it has been shown that a reserve of phosphorus has been built up in the soil that will have a decided effect for several years without further applications. When crop prices are good, fertilizer may be used in heavier applications so long as the added increments produce increases that pay for the applications; thus a reserve may be built up in the soil that will make unnecessary the use of fertilizer in periods of low crop prices, except, perhaps, for crops of high value per acre, like tobacco.

Legumes in Pastures.[5] "Legumes are just as important in mixture with pasture grasses as they are in rotation with non-

[5] From Kentucky Extension Circular 272, Soil Management for Kentucky. 1934.

leguminous crops. An experiment on the Experiment Station farm at Lexington illustrates this point. In 1923, bluegrass was sown on land that would make 50 to 60 bushels of corn to the acre. With one part of it white clover was seeded, and all legumes were kept out of the other part. Volunteer sweet clover appeared on the legume plot and was allowed to mature, after which it was removed. The next year the bluegrass was harvested. The grass with the legume yielded 2400 pounds of hay per acre, and that without the legume 870 pounds. White clover was continued with the grass where the sweet clover had been. Usually the grass was clipped and left on the ground, but it was harvested twice more. The total yield of three cuttings of grass was 6100 pounds per acre on the legume plot, and on the plot without legumes it was 2600 pounds. Analysis of the grass at the grazing stage in two different years showed that the grass grown with the legume contained 33 percent and 44 percent more protein than the grass grown alone. At the end of eight years, 18 inches of soil under the grass without the legume had gained 62 pounds of nitrogen per acre, while 70 pounds were removed in harvested and dead grass. The soil under the legume and grass mixture had gained 406 pounds, while material removed contained 278 pounds, or a gain of nearly 700 pounds per acre. Grass had almost disappeared from the non-legume plot, altho there was a little gain in total nitrogen in the first 18 inches of soil, but on the grass-legume plot the grass was vigorous.''

EXPERIMENTS IN PROGRESS

Rotation Experiments at Lexington. In 1920, rotation experiments were begun on the Experiment Station farm at Lexington (Maury silt loam) for the purpose of testing the effect of the preceding crop on wheat and for the purpose of determining the residual effect of different legumes in maintaining yields of corn and wheat. The rotations are:

1. Corn, wheat, clover.
2. Corn, wheat, orchard grass.
3. Tobacco, wheat, clover.

4. Corn, wheat, soybeans (in 28-inch rows to 1927; drilled solid since).
5. Corn, soybeans, wheat (beans in 28-inch rows to 1927; drilled solid since).
6. Corn, soybeans, wheat (beans drilled solid; cut for hay to 1927; afterwards threshed, straw returned on corn ground).
7. Corn, wheat, clover.

No fertilizer was used, as this soil is well supplied with the mineral nutrients. The plots were limed at the rate of 2 tons of ground limestone per acre, in 1927. No manure was used and no residues were returned, except as indicated in Rotation No. 6. The first year's growth of clover and of orchard grass was not harvested. A winter cover crop was always used in the soybean rotations when the ground was not occupied by a regular crop, including the wheat stubble.

The land on which this experiment is located was in soybeans in 1918, wheat in 1919, and clover in 1920. In 1920, after clover harvest, the first series of plots was plowed and planted to corn and tobacco, to get the effect of these crops in starting the rotation, but these crops are not included in this report. The second series of plots was put in corn and tobacco in 1921, following clover harvested in 1920. The yields of this year are of no value in comparing rotations. However, they have some value in showing the relative productivity of the plots occupied by the various rotations. After clover harvest in 1920, Series 300 was plowed. The appropriate plots were seeded to clover, orchard grass and wheat to complete the rotations. Red clover was used alone thru the seeding of 1930; since then, when the spring seeding failed, alfalfa was mixed with it for summer seeding. This was done four times. There were failures to get crops for harvest in 1926, 1928 and 1931. The yields of crops in these rotations are given in Table 2, on page 134

In Rotations 5 and 6 the average yields of corn thru 1928 were 46.5 bushels and 48.9 bushels, respectively—2.4 bushels in favor of No. 6. Beginning with 1928, the soybeans in Rotation 6 were threshed and the straw returned to the ground for corn the following year. The average yield of seven

TABLE 2. Yields of crops in rotation experiments.[1]

Period	Rot. 1 C-W-Cl	Rot. 2 C-W-OG	Rot. 3 Tob-W-Cl	Rot. 4 C-W-Sb	Rot. 5 C-Sb-W	Rot. 6 C-Sb-W	Rot 7 C-W-Cl
Corn, bushels; tobacco, lbs., per acre							
Average 1921-23	50.4	44.9	1477	53.1	45.9	45.6	47.5
Average 1934-36	50.8	46.4	1258	37.9	36.7	41.7	46.4
Average 15 crops[3]	59.2	54.3	1192	50.9	44.9	48.4	56.2
Wheat, bushels, per acre							
Average 1921-23	20.4	21.0	20.9	19.6	19.6	18.6	22.1
Average 1934-36	19.8	14.9	25.8	14.8	13.7	15.0	18.9
Average 15 crops	22.0	19.3	27.2	19.2	20.3	20.7	22.1
Hay, pounds, per acre							
Average 16 years	2935	1230	2633	4353	4015	........[2]	2668

[1] The corn crop of 1930 failed, and the crop of 1936 was very poor, on account of drouth. The wheat crop for 1928 was winterkilled. As there were three failures of clover and four failures of orchard grass to get large enough to cut, the hay of these crops is averaged on a basis of sixteen years for comparison with soybeans, of which there were no failures.

[2] The soybeans in Rotation 6 were cut for hay thru 1927, after which they were harvested for seed. The average yield of hay was 3943 pounds, as compared with 4000 pounds in Rotation 5. The average yield of beans in No. 6 for 1928-36 (exclusive of failure in 1930) was 13.9 bushels.

[3] For yields of crops by years thru 1931 see Ky. Exp. Sta. Bul. 331.

crops of corn affected by the returned straw was 47.8 bushels, while in Rotation No. 5 for the same period it was 43.0 bushels—4.8 bushels in favor of No. 6. The first wheat appeared in 1931 on land to which the bean straw was returned for corn. The average yields of wheat in Rotations 5 and 6 thru 1930 were 21.9 bushels and 21.5 bushels, respectively. From 1931 to 1936, the average yields were 17.7 bushels and 19.4 bushels, respectively—1.7 bushels in favor of No. 6. It appears that the return of soybean straw has affected the yields of corn and wheat favorably, but not very greatly.

In the fall of 1921 the plots of one of the three series used for the rotation were sampled for nitrogen determination, and again, in 1930, the same plots were sampled. The land slopes moderately from Rotation 7 to Rotation 1. The total gains or losses of nitrogen as pounds in 2,000,000 pounds of surface soil (7 inches) and 4,000,000 pounds of subsoil (11 inches), the approximate estimated weight of an acre of soil to those depths, were as follows:

Plot No.	Rotation	Loss or Gain Lbs.
201	Corn–wheat–clover	+ 707
202	Corn–wheat–orchard grass	— 10
203	Tobacco–wheat–clover	+ 88
204	Corn–wheat–soybeans	+ 1
205	Corn–soybeans–wheat	— 188
206	Corn–soybeans–wheat (beans drilled solid)	+ 200
207	Corn–wheat–clover	+ 347

It may occur to some one that, with the large increase in nitrogen in the soil of plots Rotations 201 and 207, assuming similar increases in the other plots of the corn-wheat-clover rotation, the yields of corn should have been higher and that the reason that they were not higher is because no fertilizers were used and a shortage of phosphorus or potassium may have developed. This experiment is on a high-phosphorus soil. That no serious shortage of potash has developed is shown by the yields in a similar rotation on adjacent land. On the unmanured check plots, the average yield for 1921–23 was 48.5 bushels against 48.9 bushels as an average of Rotations 1 and 7 for the same years. Where 10 tons of manure were used on each corn crop in duplicate tests from 1921 to 1936 the average yield was 61.8 bushels per acre against 57.7 bushels as an average for Rotations 1 and 7 for the same period. The evidence is that lack of moisture is the reason for yields not being higher. Seldom is there sufficient moisture properly distributed for maximum corn yields here. Four tons of manure on each corn crop in the above tests produced 59.4 bushels against 61.8 bushels for 10 tons, as stated above. However, such cropping practices as

are used in these rotations will ultimately develop a potassium shortage, as has been shown by other experiments.

It is evident from these results that clover is much superior to soybeans in the maintenance of nitrogen. It appears that soybeans drilled solid are more effective in nitrogen conservation than drilled in rows and cultivated. The corn yields up to the time soybean straw was returned in Rotation No. 6 were greater for Rotation No. 6, altho they were equal for the first round of the rotation.

Adjacent to these rotations is a rotation of corn, wheat and clover, in which manuring experiments are being conducted. In the experiment there are six check plots in each of the three series, to which no manure is applied. Clover failed and soybeans for hay were substituted four times (1921, 1924, 1926, 1928), while in the rotation experiments under discussion clover was always reseeded when the regular seeding failed. Altho in 1926 and 1928 the reseeding did not make sufficient growth for harvest, there was some clover which benefited the corn the following year. For the years 1922, 1925, 1927 and 1929, where corn followed soybeans substituted for clover the average yield of corn on unmanured check plots in the manuring experiment was 38.4 bushels per acre, while in the rotation experiments where soybeans were not substituted for clover the average yield of corn following the clover in duplicate rotations was 50.6 bushels per acre, an increase of 12.2 bushels, or about 32 percent greater following clover. The yields of corn on the same plots in 1924, 1926, 1928 and 1931, when corn followed clover on all of them, were 62.3 bushels on the unmanured checks in the manuring experiments and 69.4 bushels in the rotation experiments, a difference of 7.1 bushels, or about 11 percent. Observations of the growing corn accorded with the results.

The average yield of the six check plots in the manure rotation for 1921–23 was 47.8 bushels with the crop of 1922 following soybeans substituted for clover when it failed. The average yield for Rotations 1 and 7 for the same years

was 48.9 bushels—showing that little difference existed in the productivity of the soil at that time. If the 1921 and 1923 crops are compared, there is a difference of 0.7 bushels in favor of the manure rotation check plots.

These results show clearly the superior residual effect of clover to soybeans. As previously stated, the object was to get the residual effect of these rotations unobscured by any effect of manure or residues returned except as noted.

It is worthy of note that the yield of soybean hay in Rotation No. 4 was 12 tons greater in sixteen years than the yield of clover hay in Rotations No. 1 and No. 7. Had manure made from feeding the crops in both rotations been carefully saved and returned, it is probable that the yields of corn and wheat would have been as good in the soybean rotation as in the clover rotation. However, manure is seldom saved fully enough to offset the difference between the effects of the two rotations. Beginning with 1937, manure will be applied to all plots for corn and tobacco.

Legumes in Rotation at the Western Kentucky Substation. In a rotation experiment at the Western Kentucky Substation, on soil of limestone origin,[6] various legumes and timothy are used as the third-year crop in rotation with corn and wheat. The purpose of the experiment is to determine the residual effect of the legumes and grass on the yield of corn and wheat. The plan of the experiment provides that from time to time the nitrogen content of the soil shall be determined and compared with the content at the beginning of the experiment. The experiment was begun in the fall of 1926, but the corn and wheat crops of 1927 are not used in the average yields because they were not affected by preceding legumes. Limestone, where used, was applied at the rate of 2 tons per acre when the experiment was begun. Reliming was begun on the series of plots in corn in 1936 and the other two series will be relimed in 1937 and 1938. Superphosphate was used at the rate of 300 pounds (16 percent) on corn, and 300 pounds on wheat. Muriate of potash

[6] The soil has not been classified by the United States Bureau of Soils, but it is believed to be Decatur silt loam.

was applied at the rate of 100 pounds per acre on Plot 15 when wheat was sown, to determine its effect on alfalfa. Sulfate of ammonia was used on Plot 24 at the rate of 100 pounds per acre for each crop, except that it was not used on timothy prior to 1930. On Plot 20, beginning in 1929, manure has been applied for corn at the rate of 3 tons for each ton of clover hay harvested the preceding year. Table 3 gives the average yields of crops thru 1936. As corn was practically a failure in 1930 because of drouth, the yields for that year are not included in the average, for to do so would obscure to some extent the normal effects of the legumes on yields. The corn yields of 1936 were much below average, but are included. Wheat was a failure in 1928.

For some cause not determined, good stands of alfalfa and sweet clover were not obtained, and the yields were low. The yields of sweet clover seed were very low. On Plot 20, where manure was used, the average yield of clover hay was lower than on Plot 17, where manure was not used. This difference is due very largely to the difference in yield for one year when clover was a good stand on Plot 17 and yielded 4540 pounds, whereas the first seeding failed, for some unknown reason, on Plot 20, was reseeded in the spring of the year of harvest, and yielded 2100 pounds.

Outstanding results of these tests are:

1. The large effect of limestone and phosphorus on the yield of lespedeza.
2. The low yields following cowpeas and soybeans, including the plot to which soybean straw was returned.
3. The effectiveness of lespedeza, particularly on soil treated with limestone and superphosphate.
4. The effect of clover or clover and timothy as compared with timothy alone or with timothy alone and sulfate of ammonia as a source of nitrogen on all the crops in the rotation.
5. The ineffectiveness of clover plowed under as compared with clover harvested.

It will be observed that the yields of cowpea and soybean hay were larger where only phosphate was used than the yields

TABLE 3. Average yields per acre of crops in rotation with various legumes and grass (corn and wheat in bushels; hay in pounds). See footnote[1] for explanations.

Plot No.	Treat-ment	Third-Year Crop and Its Use	Corn, 8 Crops		Wheat, 8 Crops		Hay, 9 Crops	
			Yield	Increase	Yield	Increase	Yield	Increase
1	O		28.7	----	4.6	----	866	----
2	P	Lesp. plowed under	43.1	13.9	11.9	6.9	----	----
3	P	Lesp. for hay	36.9	7.2	11.0	5.5	2067	1076
4	O		30.1	----	5.9	----	1053	----
5	LP	Lesp. for hay	49.2	17.3	14.6	8.2	3489	2394
6	P	Cowpeas for hay	33.4	—0.3	8.7	2.5	3082	1946
7	O		35.5	----	6.4	----	1178	----
8	P	Soybeans for hay	35.2	—0.8	8.8	2.0	3313	2000
9	P	Soybeans for seed	39.8	3.2	10.0	2.8	4.9[2]	----
10	O		37.1	----	7.6	----	1584	----
11	LP	Sw. cl. hav 1st yr.; seed 2d yr.; straw returned	55.2	18.5	14.9	7.9	1975	413
12	LP	Alf. for hay; last crop turned under	48.7	12.5	13.6	7.2	1569	30
13	O		35.8	----	5.8	----	1517	----
13a	O		35.4	----	6.7	----	1364	----
14	LP	Alf. for hay	48.3	13.9	13.7	7.1	2162	833
15	LPK	Alf. for hay	46.5	13.0	13.2	6.6	1996	703
16	O		32.5	----	6.5	----	1258	----
17	LP	Clover for hay	53.0	18.8	16.7	9.6	2742	1346
18	LP	Clover plowed under	55.5	19.6	17.4	9.6	----	----
19	O		37.6	----	8.4	----	1671	----
20	LPM	Clover for hay	54.4	19.0	17.5	9.8	2398	882
21	LP	Timothy for hay	39.1	6.0	10.1	3.1	1880	518
22	O		30.9	----	6.3	----	1207	----
23	LP	Cl. and tim. for hay	47.8	15.1	13.6	6.6	2761	1423
24	LPN	Timothy for hay	46.7	12.1	14.5	6.7	2752	1283
25	O		36.4	----	8.5	----	1600	----

[1] O = no treatment; L = limestone; P = superphosphate; K = muriate of potash; M = manure; N = 100 pounds sulfate of ammonia used on each corn and wheat crop and on timothy since 1930.

The increases are calculated from the check plots by assuming a uniform variation between check plots.

The third-year crop on the check plots was a mixture of red and alsike clovers, common and Korean lespedeza, except the 1936 crop, which was red clover, Korean and Kobe lespedeza. However, the hay crop was practically all lespedeza.

The lespedeza on Plots 2, 3 and 5 was a mixture of common and Korean for the first four crops, Korean alone for the next four crops, and a mixture of Korean and Kobe for the 1936 crop.

[2] Seed, bushels. Straw returned.

of clover and alfalfa hay where limestone and phosphate were used. If manure were returned from feeding corn, corn stover and hay, and using straw for bedding, it is possible that the yields of corn and wheat would be as good following cowpeas or soybeans as following clover and lespedeza. Manure is not

generally well saved. Furthermore, cowpeas and soybeans are expensive to grow, because of the extra plowing of the land and the cover crop that is and should be used between them and corn in these tests, and should be used in general practice

It is quite likely also that considerable leaching of nitrogen from the soil takes place between wheat harvest and the following cowpea or soybean crop, because no winter cover crop is used on the stubble land.

In lespedeza rotations, there is no doubt considerable leaching of nitrogen from the soil in both the first and second winters following its seeding, because no winter cover crop is used. Lysimeter experiments (see Page 143) show much leaching from soil occupied by lespedeza when no grass or cover crop is used with the lespedeza. Where grass is not sown with lespedeza, a winter cover crop of grain should be seeded on the disked lespedeza stubble as early as practicable.

If lespedeza is not grazed too closely—and it is not often that this happens—enough seed matures for self-seeding where the sod is disked for a winter cover crop. If lespedeza is cut for hay early enough and high enough to leave some seed-bearing branches, it reseeds itself when disked for a winter cover crop. If it is cut after seed has matured and it is desired that it reseed itself, care will have to be taken to cut it high enough to leave some seed. Where the stand is very thick, as is generally the case with a self-seeded crop, there may not be any seed low enough on the plants for self-seeding when cut for hay.

Perhaps the largest amount of nitrogen fixed was on Plot 5, but conditions were favorable for leaching there because of the dead legume material left on the ground in the first year's growth of lespedeza, which was not harvested, and in the second-year stubble. Conditions were favorable for leaching on Plot 11 also, with the sweet clover dead and the straw lying on the ground. Had winter cover crops been sown on all the plots preceding corn, the gains and losses of nitrogen doubtless would have been different. The purpose was to test usual practices.

A study was made of the nitrogen content of the first 18

inches of the soil of each plot in one of the three series used in this rotation. Soil samples were taken from each plot at the beginning of the experiment, and samples were taken again from near the same places on each plot in September, 1936, following corn. Samples for similar studies will be taken following the corn crops in 1937 and 1938. Total gains or losses of nitrogen as pounds in 2,000,000 pounds of surface soil (7 inches) and 4,000,000 pounds of subsoil (11 inches), the approximate estimated weight of an acre of soil to those depths, were as follows for the plots sampled in 1936:

	Gain (+) or Loss (—) Lbs.
Average of all check plots	— 179
Plot 2—Lespedeza plowed under	+ 41
Plot 3—Lespedeza for hay	— 207
Plot 5—Lespedeza for hay	— 31
Average of Plots 6 and 8—cowpeas and soybeans for hay	— 220
Plot 9—Soybeans for seed, straw returned	+ 52
Plot 11—Sweet clover (see Table 2)	+ 86
Average of Plots 12, 14, 15—alfalfa for hay	+ 49
Plot 17—Clover for hay	+ 149
Plot 18—Clover plowed under	+ 72
Plot 20—Clover for hay, manure on corn	— 60
Plot 21—Timothy for hay	— 60
Plot 23—Clover and timothy for hay	+ 153
Plot 24—Timothy for hay, 100 lbs. sulfate of ammonia on each corn and wheat crop and on timothy since 1930	+ 131

The net gain or loss of nitrogen does not, of course, tell how much was lost by leaching. However, when considerable dead material is left on the ground, as was the case with all the legumes in these tests except alfalfa, there will be loss of nitrogen by leaching.

Where lespedeza is to be used for pasture or hay, without doubt its best use is in mixture with grass. In general, under Kentucky conditions, a three-year rotation is too short if enough land is available to extend it. The rotation should be lengthened as much as practicable by growing grass with the

legume and using the mixture for pasture and hay as long as conditions permit. By producing plenty of pasture and hay by good soil treatment, livestock can be maintained a much longer period on pasture and with less grain and concentrates the remainder of the year. Good cover crops may also be used for pasture and further reduce the grain required for feed. Pasture and hay produced on properly limed and fertilized soil are also more nutritious than when produced on soil deficient in plant-food elements. The value of good pasture and hay is strikingly illustrated in the Bluegrass region, where in some counties three-fourths or more of the land is kept in grass for pasture and hay. Also, this method of cropping is the best preparation of soil for both Burley and dark tobacco. While complete fertilizers are profitable on tobacco under most conditions, they cannot take the place of good soil management in preparing the land for the crop.

Lysimeter Experiments. Lysimeter experiments were begun at Lexington in October, 1933, with Maury silt loam. The soil container part of the lysimeters is 22 inches in diameter and 24 inches deep, with a basin under the soil, separated from it by a perforated iron plate. The drainage water is removed from the basin by pumping thru an iron pipe leading from the basin to the top of the lysimeter. All lysimeters except one pair were seeded to rye in October, 1933, with the following crops on duplicate lysimeters thereafter.

None	
Bluegrass	Korean lespedeza and winter cover crop of rye.
Korean lespedeza	Korean lespedeza and bluegrass.
White clover	White clover and bluegrass.
Red clover	Red clover and bluegrass.
Alfalfa	Alfalfa and bluegrass.

The object of the experiment is to determine losses from leaching under the different crops and to determine nitrogen fixation and accumulation in the soil, the hypothesis underlying the experiment being that, in addition to preventing leaching of nitrogen, grass in association with the legume may, by competi-

tion for soil nitrogen, cause greater fixation by the associated legume. The experiment has not been under way long enough to provide sufficient data to draw conclusions for all the tests involved, but certain results are significant enough to warrant their publication at this time.

Because of failure of bluegrass to make a stand with lespedeza, there were six lysimeters that had practically only lespedeza on them in the fall of 1934. These were handled in duplicate in different ways, with the results indicated below.

	Nitrogen leached Oct. 1, 1934, to June 30, 1935
Korean lespedeza undisturbed	56 lbs. per acre
Korean lespedeza disked into soil Oct. 1 and seeded to rye	2 lbs. per acre
Korean lespedeza disked into soil Oct. 1, no cover crop seeded	127 lbs. per acre

In the fall of 1935 the Korean lespedeza on two lysimeters was clipped and removed, leaving a stubble about 2 inches high, without a winter cover crop. The average nitrogen leaching from these two lysimeters was:

October 1, 1935, to March 31, 1936,	48 lbs. per acre
April 1, 1936, to June 30, 1936,	14 lbs. per acre
Total	62 lbs. per acre

The middle of September, 1934, a crop of Korean lespedeza yielding perhaps 2 tons of hay per acre was disked into the soil in small duplicate plots on the Experiment Station farm. No cover crop was seeded. The average amounts of soluble (nitrate) nitrogen at different dates thereafter were as follows:

Depth, inches	Nov. 30	Jan. 7	Mar. 4	April 10
0–6	16.4	25.4	9.7	4.7
6–18	11.4	21.8	19.3	6.1
18–30	—	—	20.0	8.3
30–42	—	—	—	6.1
42–54 (rock)	—	—	—	3.3
Totals	27.8	47.2	49.0	28.5

Precipitation during the period, in inches, was: October, 0.68; November, 3.41; December, 2.51; January, 5.11; February, 1.87; and March, 7.52. Precipitation was less than normal except during January and March, and hence leaching probably was less than during an average year.

In the same study there were other plots where the Korean lespedeza was disked in and rye seeded. Very little soluble nitrogen was found in the soil at any time, and none after November 30.

The following results from certain other lysimeters are significant:

	Loss of Nitrogen Oct 10, 1933, to Mar. 31, 1936
No vegetation	310 lbs. per acre
Bluegrass	17 lbs. per acre
Alfalfa	15 lbs. per acre
Alfalfa and bluegrass	7 lbs. per acre
Korean lespedeza and bluegrass	86 lbs. per acre

The Korean lespedeza kept the bluegrass from making much growth, so that the cover was mostly lespedeza. However, it is quite certain that where lespedeza is in mixture with a good stand of grass, practically all leaching of nitrogen will be prevented.

The drainage from the lysimeters was, of course, greater than from 2 feet of soil in natural position, for the reason that in the lysimeters there is no resistance to drainage from underlying soil, and also for the reason that there is little or no surface run-off from lysimeters, while from a soil in natural position, which nearly always has some slope, there is a great deal of surface run-off. The surface of the soil in the lysimeters is level and a little below the top of the cylinder walls. However, while losses from soils in natural position are not so great as in lysimeters, doubtless the losses vary under different crop cover conditions just as they do in lysimeters. It is well to remember that in the limestone regions of Kentucky water passes thru the soil and

is carried away rapidly thru the underground passages characteristic of a limestone area.

Effect of Legumes on Bluegrass. Studies are being made on the effect of various legumes on the yield of bluegrass on the Experiment Station farm at Lexington. Following is a brief summary of some of the more important results obtained. The yields are of cured material on the basis of 10 percent of moisture in the hay.

1.	Bluegrass alone (average 1930-34)	1945 lbs. per acre
2.	Bluegrass from plots on which legumes were associated with bluegrass but had disappeared before the harvest of bluegrass crops used in this average (average 1930–34)	2950 lbs. per acre
3.	Bluegrass alone (average 1929–35)	1977 lbs. per acre
4.	Bluegrass with which red clover, white clover, sweet clover, lespedeza and alfalfa were seeded in the beginning, but from which the legumes wholly or partially disappeared. Legumes except red clover, and sweet clover included in harvest with grass until disappearance (average 1929–35)	3580 lbs. per acre

THE UTILIZATION AND CONSERVATION OF NITROGEN

It is the opinion of the writer that, under Kentucky conditions, the fixation, utilization and conservation of nitrogen is the largest problem in soil improvement and conservation for the following reasons:

1. Crops generally require more nitrogen than any other nutrient element that may have to be applied to the soil and, if purchased, would usually cost more per unit of crop produced.

2. Nitrogen is more subject to loss by leaching than are other nutrient elements that have to be applied to Kentucky soils, for the reason that whenever the weather is warm enough for plant growth, soil organic matter decomposes and soluble nitrogen is developed in the soil and is subject to leaching unless there is some growing crop on the land that will use it all.

3. In the process of becoming soluble, nitrogen is converted into nitric acid, a very strong acid which combines with important elements in the soil, such as calcium (lime) and potassium, among other elements, to form soluble compounds which are subject to leaching, thus causing a loss of these mineral nutrients as well as of nitrogen.

The only means of preventing these losses is to have the land covered as much of the time as possible with a growing crop. The ideal cover is a mixture of grass and legumes. Any perennial grass may be used, such as timothy, redtop and orchard grass. Where the land can lie in grass for several years, the ideal grass is bluegrass, provided the land is put in condition for growing it.

Practically any soil in the State, if it is limed and liberally fertilized with phosphate, will produce good bluegrass when legumes are grown with it, as has often been demonstrated. In regular rotations containing intertilled crops like corn and tobacco the intertilled crops should be followed by grass and legumes for as long a period as practical (see Kentucky Extension Circular 272 for suggestions on rotations).

All intertilled crops should be followed by winter cover crops, which should be seeded as early as possible, so that they may make a large growth and take up as much nitrogen as possible. If the land is rich and barley can be seeded by September 15, it has no superior as a cover crop, except that it sometimes winterkills. Both rye and wheat are good cover crops. The importance of cover crops and of early seeding is well illustrated by the following experiments formerly reported.[7]

On fertile soil on the Kentucky Experiment Station farm at Lexington, on which tobacco was grown, barley was sown after the tobacco was removed, while a small area was left bare. On November 30 the barley had taken up 156 pounds of nitrogen per acre, with 19 pounds per acre of soluble nitrogen left in the first 8 inches of soil. In the bare soil there were 69 pounds of soluble nitrogen per acre in the first 8 inches, a difference of

[7] Kentucky Extension Circular 272. Soil Management for Kentucky.

106 pounds of nitrogen that presumably had already passed below the first 8 inches of soil by November 30. Other tests on the farm showed that most of the soluble nitrogen in the soil in the fall passes below the first 2 feet of soil by the last of March. The nitrogen lost from the soil without a cover crop was 156 pounds greater than with the cover crop, an amount equivalent to about 1000 pounds of nitrate of soda or 800 pounds of sulfate of ammonia.

A similar test was made on a less fertile soil on the Kentucky Experiment Station farm, in which certain cover crops were sown at different dates following the harvesting of tobacco. The results were as follows:

	Nitrogen per acre in plants and soluble nitrogen in 2 feet of soil in December	
Crop and Date of Sowing	In plants	In soil
Barley seeded September 11	46 lbs.	3 lbs.
Barley seeded October 10	20 lbs.	19 lbs.
Wheat seeded October 10	10 lbs.	32 lbs.
Wheat seeded November 7	2 lbs.	35 lbs.

By the end of the following March, practically all the soluble nitrogen had disappeared from the first two feet of soil. In this test the nitrogen lost from ground seeded to wheat on October 10 was the equivalent of 200 pounds of nitrate of soda, while there was practically no loss from the land seeded to barley on September 11.

Many soils in the State have become so exhausted of organic matter (humus) that there is not much nitrogen left in them to become soluble and leach, and they therefore do not produce a cover crop vigorous enough to prevent erosion, which is also a cause of great loss of soil and therefore of all plant nutrients. One highly important reason for keeping up a good supply of nitrogen by growing legumes is that a crop cover can be grown vigorous enough to prevent erosion. If ground is so worn that it will not support a good cover, then the imperative thing to do is to begin to improve it by growing legumes. In most cases of

this kind, success will be dependent upon liming and phosphating the land for the legume.[8]

Important in conserving and utilizing nitrogen fixed by legumes is the proper saving and utilizing of manure made by feeding legumes and other crops. A large part of the nitrogen and potassium in the feed given to animals is voided in the urine. Unless sufficient bedding is used, large losses occur; and unless the manure is protected against heating and leaching, there will be large losses of nitrogen even if all the urine is absorbed by bedding.[9]

It is best to apply manure to non-legume crops in the rotation, principally on corn and tobacco in general farming. If manure is applied for a legume, it may furnish a considerable part of the nitrogen required by the legume and reduce the amount taken from the air. Manure applied to corn is not completely used by the corn. If soybeans or cowpeas or other legumes follow the corn, they may take a considerable part of their nitrogen from the residue of manure, and therefore fix less from the air. It seems to the writer that cowpeas and soybeans should be used primarily as emergency crops when other legumes fail, and that it is better to follow corn and tobacco with small grain in which grass and legumes will be sown to remain for two years or longer. For example, it is better to use a rotation of corn, wheat, and two years of legumes and grass than to use a rotation of corn, soybeans, wheat and clover.

Manure dropped on pasture land is generally poorly utilized because the dunghills are not scattered. When not scattered, the concentration on small plots is much greater than is needed, and animals do not eat readily the more vigorous grass around the dunghills, as is readily observed on many bluegrass pastures. The dunghills may be broken up and scattered by various dragging devices that the farmer may make. A section harrow may be adjusted for the work. One device consists of a

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[8] Kentucky Experiment Station Bulletin No. 322 gives the results of practical experiments in improving worn soil.

[9] See Kentucky Extension Circular No. 153 on the production and care of farm manure.

number of old automobile tire rims loosely bolted together to form a flexible drag.

Manure spread in warm weather, as in the spring for corn and tobacco, should at once be well disked into the soil, as it may contain nitrogen in the form of ammonia, a large part of which may be lost by volatilization on a warm day. When put out in the field in small piles, losses will take place by volatilization, and if rained upon, loss of effectiveness will take place by leaching into the small area under the pile.

Stalks, straw and other crop residues are best utilized for bedding. They absorb urine, which makes them decompose more effectively than if applied directly to the soil. Stalks and straw plowed under on unmanured land may lower the yield of the first crop following.

SUMMARY AND SUGGESTIONS

The solution of the problem of the fixation, utilization and conservation of a sufficient supply of nitrogen involves many factors of vital importance.

1. An ample supply of nitrogen is necessary to the maintenance of a vigorous ground cover to prevent soil erosion and all its attendant evils.

2. With an abundance of nutritious pasture and hay, livestock will require less grain feed, and not so much land has to be plowed for corn, thus protecting more land against erosion and leaching. The effect of pasture and hay in reducing tilled crops is well illustrated in the better parts of the Central Bluegrass region, where two-thirds to three-fourths of the land is kept in grass and a large livestock population is maintained. The type of agriculture in which grass predominates is also best for both Burley and dark tobacco, Kentucky's chief cash crops.

3. The production of legumes to supply nitrogen for high yields of non-leguminous crops, including grasses, implies the application of sufficient mineral nutrients in which the soil may be deficient to make a vigorous growth of legumes possible. They are principally lime and phosphorus.

4. The conditions necessary for the production of vigorous legumes are also necessary for the production of crops of high nutritive value. Crops, including legumes, produced on soil deficient in mineral plant nutrients contain, as a rule, lower percentages of nitrogen (and therefore less protein) and mineral nutrients necessary to the proper nourishment of farm animals and human beings than do crops produced on fertile soil. The primary object of the production of human food and animal feed crops is human nutrition. Neither animals nor human beings can be properly nourished upon crops grown upon impoverished soil. It is an obligation to the present and future generations to conserve the soil in a fertile condition for the production of highly nutritious food and feed plants.

Use of Steep Land. Where a large part of the farm is steep and subject to erosion, it is advisable to keep as much as possible of the steep land in pasture and hay crops, giving it the necessary treatment to make it favorable for vigorous growth of the crops. The grasses used should always have legumes with them. Under these conditions it is advisable to produce the necessary grain for feed on the more level land, in short rotations, making the land as productive as is economically feasible. A two-year rotation of corn and small grain may be used. Barley may be used if the land is fertile and the corn is harvested early enough, as may be done when it is used for silage or when an early variety is used for grain, thus getting two grain feed crops each year.

A two-year rotation of corn and wheat on the Hopkinsville soil experiment field[10] illustrates the possibilities of such a rotation. Rather thin land was limed and treated with superphosphate. Sweet clover was sown on the wheat in the spring and turned under the next year for corn. The yield of corn for the first three years (1922–24) was 25.5 bushels per acre, and for the last three years (1927–29) was 54.7 bushels. Manure was used on the corn in 1926-27 at the rate of 6 tons per acre. The average yield of corn for the eight years was 43.2 bushels. Reg-

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[10] See Kentucky Experiment Station Bulletin No. 299, a report on the Hopkinsville soil experiment field, which was operated from 1922 to 1929.

ular use of manure would no doubt have greatly increased the yields, but it was not regularly obtainable.

In a three-year rotation of corn, wheat and red clover on adjacent land not limed or phosphated, the yield of corn for the first three years was 18.9 bushels per acre, and for the last three, 31.1 bushels. In the three-year rotation on land treated with limestone and superphosphate, the yield was 24.8 bushels for the first three years and 49.4 bushels for the last three. Manure was used at 5 and 6 tons per acre on the corn in 1927-28, on both the fertilized and unfertilized plots.

While the effects of the two rotations on the yield of corn are not strictly comparable, because the productivity of the soil differed somewhat in the different cases cited, the very large increase in the yield of corn is highly significant and indicates the possibilities of a short rotation. Lespedeza may be used instead of sweet clover, but it should be followed by a cover crop, which may be seeded by disking the sod. It may also be mixed with sweet clover. Sweet clover should be plowed under by the last of April when it is to be followed by corn. The land in a short rotation like this should be liberally manured if possible. If barley is used, it may be advisable to top-dress with nitrogen, for it requires a liberal supply of nitrogen.

It is not best to try to produce corn in continuous culture, even tho the land may be liberally manured. An experiment on the Experiment Station farm at Lexington[11] indicates that it is not possible to maintain a high yield of corn in continuous culture, tho the land is fertile to begin with and is liberally manured thereafter. The experiment was begun in 1920, on land that yielded 70 bushels per acre the first year, without manure or fertilizer. Fifteen tons of manure per acre had practically no effect on yield the first year. The average yield of the unmanured check plots for eleven crops was 32.6 bushels per acre, while on the plot manured at the rate of 15 tons per acre in alternate years the yield was 45.5 bushels per acre. Ten tons of manure was as effective as 15 tons. A rye

[11] See Kentucky Experiment Station Bulletin 331.

cover crop was used each winter. In a three-year rotation of corn, wheat and clover begun at the same time on adjoining land not quite so fertile, the average yield for the same period was 51 bushels per acre without the use of manure and 60 bushels per acre with the use of 4 tons of manure per acre for each corn crop.

Care in Use of Lime. While it is important to use lime to produce a satisfactory growth of legumes, it is very important not to lime land heavily on which tobacco is to be grown, and not to apply lime immediately preceding tobacco, for such practices may injure tobacco, altho injury does not always follow these practices. The lime should be applied as far ahead of tobacco as can be done in preparing the land for tobacco, and should be used at as low a rate as will produce the legume. One ton of ground limestone per acre is usually sufficient for this purpose, but there is little danger from 2 tons if four or five years intervene between its application and the tobacco crop.

Advantages of Alfalfa. Alfalfa has advantages for a hay crop that have not been fully recognized by Kentucky farmers. It can be grown on any soil with good underdrainage, provided it is supplied with sufficient lime and mineral nutrients. One of its chief advantages is its adaptation to Kentucky rainfall conditions that often produce critical periods that prevent getting a stand of other legumes, like red clover, or may make lespedeza hay crops very short. Alfalfa may make a good first cutting, survive a severe summer drouth, and produce another good cutting in the fall, as was the case in 1936, when second-year alfalfa in a four-year rotation of corn, wheat and two years of alfalfa produced 5185 pounds of hay per acre in three cuttings. The first-year alfalfa produced 2825 pounds per acre in two cuttings. The stand was not injured by the severe drouth. Another very great advantage of alfalfa is its long life, and therefore the small cost of seeding when the number of cuttings is considered.

Where alfalfa is regularly grown on a farm, it should be rotated and not kept more than about four years on the same land. It is good practice to sow a grass with alfalfa, particu-

larly on sloping land. It is an excellent way to get a good stand of bluegrass, which prevents erosion and makes good pasture when the alfalfa is no longer used for hay. When alfalfa is plowed up, the land should be liberally manured or fertilized with mineral fertilizers before going back to alfalfa, for it makes a very heavy draft on mineral nutrients, particularly potash.

Adapted Red Clover. Red clover is an excellent legume for general cropping systems where the soil is put in condition for growing it by proper liming and fertilizing. However, many failures of clover occur on land properly prepared for it because unadapted seed is used. The Kentucky Experiment Station is making extensive tests of the adaptation of clover from various sources. The tests on the Western Kentucky Substation are illustrative of the importance of using seed of adapted strains. The results given below are the averages of the first cuttings for four years:

	Lbs. of Hay Per Acre
Adapted Kentucky-grown seed	4375
Unadapted Kentucky-grown seed	2510
Tennessee anthracnose-resistant seed	3800
Seed from northern states	2735
Seed from northwestern states	2195
Seed from European countries	2040

In 1932, when only Kentucky-grown seed was used in the tests, the adapted strains yielded 5260 pounds per acre for the first cutting and 2930 pounds for the second cutting, a total of a little more than 4 tons per acre. In the drouth year of 1936, clover from Kentucky-grown adapted seed yielded 2518 pounds of hay per acre for the first cutting on the Experiment Station farm at Lexington, while the first cuttings from foreign and northwestern United States seed averaged 965 pounds per acre. At the Western Kentucky Substation, the yield of hay from Kentucky-grown adapted seed was 5500 pounds per acre, and from northwestern United States seed it was 3450 pounds.